Transversely polarized Λ production[1]

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Abstract. Transversely polarized Λ production in hard scattering processes is discussed in terms of a leading twist T-odd fragmentation function which describes the fragmentation of an unpolarized quark into a transversely polarized Λ. We focus on the properties of this function and its relevance for the RHIC and HERMES experiments.

INTRODUCTION

Transverse polarization distribution and fragmentation functions parameterize transverse spin effects in hard scattering processes. The question is which of these functions might be relevant for the description of the single transverse spin asymmetry in the process $p\,p \to \Lambda^\uparrow\,X$ [1]? The fact that in this asymmetry the transverse spin and the transverse momentum appear to be correlated –they are orthogonal to each other–, indicates that a so-called T-odd function is required.

T-ODD FRAGMENTATION FUNCTIONS

In case there are two large scales ($\sqrt{s}$ and p_T) present in processes like $p\,p \to \Lambda^\uparrow\,X$ and $p\,p^\uparrow \to \pi\,X$ [2], the description factorizes into a hard subprocess cross section convoluted with two types of soft physics correlation functions. The latter characterize the distribution of quarks inside a hadron (Φ) and quarks fragmenting into

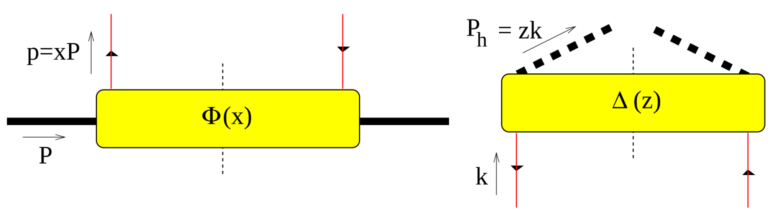

FIGURE 1. The correlation functions $\Phi(x)$ and $\Delta(z)$.

a hadron plus anything (Δ), see Fig. 1. As a function of the lightcone momentum fraction x, Φ is given by (after imposing parity and time reversal)

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$$\Phi(x) = \frac{1}{2}\left[f_1(x)\,\not{P} + g_1(x)\,\lambda\gamma_5\,\not{P} + h_1(x)\,\gamma_5\,\not{S}_T\,\not{P}\,\right]. \tag{1}$$

The transversity function h_1 [3] is the distribution of transversely polarized quarks inside a transversely polarized hadron. Similarly, the fragmentation correlation function $\Delta(z)$ [4] is parameterized as

$$\Delta(z) = \frac{1}{2}\left[D_1(z)\,\not{P} + G_1(z)\,\lambda\gamma_5\,\not{P} + H_1(z)\,\gamma_5\,\not{S}_T\,\not{P}\,\right]. \tag{2}$$

The transversity fragmentation function H_1 is the probability that a transversely polarized quark fragments into a transversely polarized (spin-1/2) hadron plus anything. The transversity functions h_1 and H_1 are not sufficient to describe single spin asymmetries. But if one includes transverse momentum dependence [3], then T-odd functions can lead to unsuppressed single spin asymmetries (for a detailed explanation cf. Ref. [5]). The transverse momentum dependent fragmentation functions[2] are defined through the parameterization of the correlation function $\Delta(z, \boldsymbol{k}_T)$

$$\Delta(z, \boldsymbol{k}_T) = \text{T-even part} + \frac{1}{2}\left[D_{1T}^{\perp}\,\frac{\epsilon_{\mu\nu\rho\sigma}\gamma^{\mu}P^{\nu}k_T^{\rho}S_T^{\sigma}}{M} + H_1^{\perp}\,\frac{\sigma_{\mu\nu}k_T^{\mu}P^{\nu}}{M}\right]. \tag{3}$$

The fragmentation functions $D_{1T}^{\perp}$ and $H_1^{\perp}$ are T-odd functions, linking transverse spin –of a hadron and quark, respectively– and transverse momentum with a specific orientation (handedness), cf. Figs. 2 and 3. There are a few experimen-

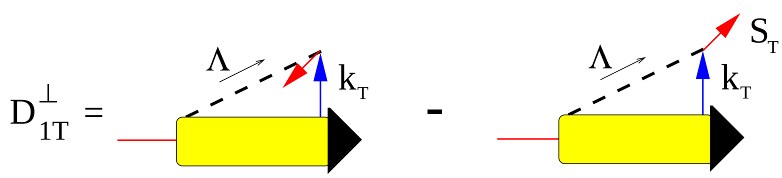

FIGURE 2. The function $D_{1T}^{\perp}$ signals different probabilities for $q \to \Lambda(\boldsymbol{k}_T, \pm\boldsymbol{S}_T) + X$.

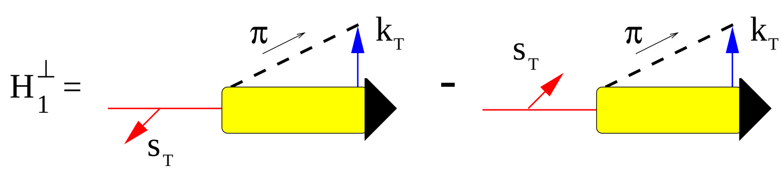

FIGURE 3. The function $H_1^{\perp}$ signals different probabilities for $q(\pm\boldsymbol{S}_T) \to \pi(\boldsymbol{k}_T) + X$.

tal indications that the "Collins effect" function $H_1^{\perp}$ [6] is indeed nonzero [7–9]; it can account for a number of different pion production asymmetries, including $p\,p^{\uparrow} \to \pi\,X$ [10]. The chiral-even function $D_{1T}^{\perp}$ [11] is expected to be relevant for transversely polarized Λ production [12], e.g. in $p\,p \to \Lambda^{\uparrow}X$.

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[2] Due to the problematic nature of T-odd *distribution* functions [6], here we will focus only on T-odd *fragmentation* functions, which are expected to arise due to final state interactions, rather than due to time reversal symmetry violation.

TRANSVERSELY POLARIZED Λ PRODUCTION

The single transverse spin asymmetry

$$P_N = \frac{\sigma(p\,p \to \Lambda^\uparrow X) - \sigma(p\,p \to \Lambda^\downarrow X)}{\sigma(p\,p \to \Lambda^\uparrow X) + \sigma(p\,p \to \Lambda^\downarrow X)} \tag{4}$$

exhibits similar behavior as the pion production single spin asymmetries, namely the magnitude grows as a function of p_T and x_F. The BNL-RHIC collider can reveal whether $p\,p \to \Lambda^\uparrow X$ persists at larger values of $\sqrt{s}$ and p_T, which would be an important indication that a factorized picture should be applicable. Such a factorized description (requiring $p_T \gtrsim 1$ GeV) in terms of the quark fragmentation function $D_{1T}^\perp$ would imply that the production of a transversely polarized Λ is independent of the details of the initial state and unlike existing models of the above asymmetry [13,14], one could restrict to the modeling of $D_{1T}^\perp$. A detailed study of $p\,p \to \Lambda^\uparrow X$ within the factorized picture will be presented in Ref. [12]. Here we want to indicate how a fit of $D_{1T}^\perp$ from that data can be used to compare to possible future $\ell\,p \to \ell'\,\Lambda^\uparrow X$ data and to $e^+ e^- \to \Lambda^\uparrow \,\mathrm{jet}\, X$ data.

1) Recently, an asymmetry in $e\,p \to \Lambda^\uparrow X$ was reported [15] (preliminary): $P_N = 0.066 \pm 0.011 \pm 0.025$ (arising mainly from $e\,p \to e'\,\Lambda^\uparrow X$ events with $Q^2 \simeq 0$). If such an asymmetry would also be found in the semi-inclusive DIS process $e\,p \to e'\,\Lambda^\uparrow X$ (for $Q^2 \gtrsim 1\,\mathrm{GeV}^2$) the factorized description [11] would imply[3]

$$\frac{d\Delta\sigma(e\,p \to e'\,\Lambda^\uparrow X)}{d\sigma(e\,p \to e'\,\Lambda\, X)} = \sin(\phi_{S_T^\Lambda} - \phi_{P_T^\Lambda})\; P_N, \tag{5}$$

where the analyzing power P_N is a function of f_1, D_1 and $D_{1T}^\perp$. If one makes an Ansatz inspired by a model for the Collins function [6] (η, M are free parameters and Gaussian transverse momentum dependence of the unpolarized fragmentation function D_1 is assumed):

$$D_{1T}^\perp(z, \boldsymbol{k}_T^2) = \eta \frac{M M_\Lambda}{\boldsymbol{k}_T^2 + M^2} D_1(z, \boldsymbol{k}_T^2) \implies P_N \approx \frac{2\,\eta\, M\, Q_T}{Q_T^2 + 4M^2}. \tag{6}$$

This exhibits plausible behavior as a function of the transverse momentum (Q_T) of the Λ and this expression for P_N can be used to fit $D_{1T}^\perp$, allowing for a check of the universality of $D_{1T}^\perp$ if compared to the resulting fit from $p\,p \to \Lambda^\uparrow X$ data.

2) In the case of $e^+ e^- \to \Lambda^\uparrow \,\mathrm{jet}\, X$, one determines the transverse momentum (Q_T) of the Λ compared to the jet (or thrust) axis. In the factorized picture with transverse momentum dependent functions this will yield a contribution [17]

$$\frac{d\sigma(e^+e^- \to \Lambda^\uparrow \text{ jet } X)}{d\Omega dz dQ_T} \propto \sin(\phi_{P_T^\Lambda} - \phi_{S_T^\Lambda}) \frac{Q_T}{M_\Lambda} \sum_{a,\bar{a}} e_a^2\; D_{1T}^{\perp a}(z, z^2 Q_T^2). \tag{7}$$

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[3] The chiral-even function $D_{1T}^\perp$ can also be probed in charged current exchange processes; for the cross section expressions in semi-inclusive DIS we refer to [16].

Note that the exponential fall-off of the function at larger values of Q_T wins out over the explicit power of Q_T (all under the requirement of $Q_T^2 \ll Q^2$). Also we note that for $e^+ e^- \to Z \to \Lambda^\uparrow \,\mathrm{jet}\, X$ transverse Λ polarization has been measured to be small (at the percent level) [18]. We expect two effects to contribute to the suppression of the above contribution at large scales such as $Q = M_Z$. The function $D_{1T}^\perp$ might be a decreasing function of Q^2, although this is not yet known. Also, transverse momentum dependent azimuthal asymmetries suffer from effective *power* suppression due to Sudakov factors [19]. The LEP result would then not contradict a possibly large asymmetry in $e\,p \to e' \Lambda^\uparrow X$ at lower energies (measurable at HERMES).

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